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The following document contains analysis from three members of the Professional Advisory Panel from the Skyscraper Safety Campaign. They have provided their comments and reviews on the NIST WTC Investigation thus far.

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# I.

## **Jake Pauls' Comments on NIST Special Publication 1000-5, Progress Report on the Federal Building and Fire Safety Investigation of the World Trade Center Disaster, June 2004**

October 6, 2004

*These comments are based on a preliminary review focusing on evacuation, means of egress and related occupant behavior as addressed in the Executive Summary, Preface, Chapters 1, 2 and 3, plus Appendices A, N and O. The comments are separated into two groups: those dealing generally with these focus areas and those dealing with the topic of remoteness of exit stairways. The former are covered in the order of the overall set of documents beginning with the Preface, Executive Summary plus four chapters and then the appendices, A-Q. In addition, an appendix is provided with some comments pertaining to use of journalist's data and to Appendix N of the Progress Report, dealing with analysis of first-person accounts.*

*A frequently asked question in these comments is along the lines of "Where in the Progress Report is this addressed?" There appear to be some glaring holes in the coverage of central building design issues in the disaster and these are particularly identified here in relation to means of egress. (In relation to this, why were no bookmarks provided for the pdf files? Given that the Table of Contents was separated from each section and no general index was provided, this reviewer—using only the pdf files for review and thus able to do many, many electronic searches—resorted to creating his own bookmarks for selected pdf files so that some of the well-buried information, if it even existed, would be easier to retrieve.)*

### **Progress Report Executive Summary**

The Executive Summary twice refers to "independent investigation objectives" but Preface refers to "interdependent projects." Are these supposed to be independent or interdependent? This is not a trifling question. A basic criticism of the Progress Report is the apparent lack of integration of the various studies being performed of the World Trade Center disaster. It appears that, given NIST's publications and presentations thus far, the final report will fail to tell a complete, compelling narrative of what happened, addressing (as in journalism) the where, when, what, who and why questions (augmented with "why not" and "with whom" questions that appear to be especially important in the case of the World Trade Center and the Port Authority). With the progress report, we are beginning to get snowed under with a lot of isolated—*rather than connected*—technical details that say more about the technical capabilities and interests of NIST staff than about what happened with the World Trade Center between the mid 1960s and the morning of September 11, 2001. As well as revealing that, for some aspects of the disaster such as nature and use of means of egress, NIST has little well-established competence, the Progress Report reveals at least one glaring omission in the investigation—the layout of tower floors that placed exit stairways much too close together. This should have been addressed in an integrated fashion, pulling together issues such as original design considerations, code compliance, construction robustness, aircraft impact and evacuation options.

Generally, throughout the Progress Report, rather than dealing with key issue such as remoteness of exit stairways, NIST focuses on issues such as the collapse of the towers and WTC 7—that is, topics where NIST has maintained relatively strong technical competence. (The focus on the collapses, while interesting as rare events in engineering terms, ignores the apparent fact that many, *if not most*, of the fatalities occurred before the collapses.) Also noteworthy is the relatively extensive, highly detailed discussion of how the aircraft and the impact into the towers are modeled (Appendix C); contrast this with the relatively sparse treatment of the means of egress system and its usage. The scope of investigations such as on the WTC should not be limited to only those areas where NIST has pared down its competence due to its economic constraints and the technical inclinations of its staff. Means of egress has gotten short shrift at (from) NIST over the last few decades (and this has been observed—and repeatedly decried—by Jake Pauls partly from his perspective as the staff member of NIST’s Canadian counterpart, the National Research Council of Canada, most responsible for extended studies of means of egress between 1967 and 1987).

The Executive Summary section on evacuation and emergency response (page 42) reports that “The initial population of each tower was similar: 8,900 ( $\pm$  750) in WTC 1 and 8,500 ( $\pm$  900) in WTC 2” and that this is “based on information and data gathered during the first-person interviews of WTC surviving occupants.” How can such data be derived from interviews with surviving occupants, especially as there were only about 225 of these (according to a presentation on June 23, 2004, by Project Leader Jason Averall)? How and why are such population estimates better than the ones by USA Today reporter, Dennis Cauchon, in December 2001? The process by which a small number of interviews led to NIST’s estimate of occupancy is not described here or, apparently, elsewhere in the Progress Report, including in Chapter 1 (which, for Finding 2.1, on page 21, mostly just repeats what the Executive Summary states) and especially in the appendices which, for most other topics, are relatively detailed. Similarly, on page 43, reference is made to predictions of evacuation time for various populations, using egress models, but where is the detail on such models and the input assumptions?

The Executive Summary ends with a section on forthcoming recommendations, introduced by the remark:

“NIST does not set building codes and standards, but provides technical support to the private sector and other government agencies in the development of U.S. building and fire practices, standards, and codes. NIST recommendations are given serious consideration by private sector organizations that develop national standards and model codes—which provide minimum requirements for public welfare and safety. The NIST building and fire safety investigation of the WTC disaster has not yet formulated recommendations. However, in formulating its recommendations, NIST will consider the following:

- Findings from the first three independent investigation objectives related to building performance, evacuation and emergency response, and procedures and practices. . . .

NIST urges organizations responsible for building and fire safety at all levels to carefully consider the interim findings contained in this report. NIST welcomes comments from technical experts and the public on the

interim findings presented herein.”

Generally, given the relatively light treatment of evacuation and means of egress issues in the Progress Report, especially in the appendices, what does NIST expect to get by way of comments from technical experts other than expressions of frustration and criticism? How does NIST hope to come up with code-related recommendations by December 2004, especially as important groundwork—which should have been done by June 2004, apparently largely by outside consultants—appears seriously incomplete.

## **Chapter 1**

An example of apparently blinkered thinking by NIST appears on page 4 of Chapter 1 in relation to item 2 of Finding 1a.1: “After breaching the building’s exterior, the aircraft continued to penetrate into the buildings, damaging core columns with redistribution of column loads to other intact core and perimeter columns via the hat truss and floor systems;” there is apparently no mention here of the devastation caused simultaneously to the three exit stairways which effectively trapped many people above the impact area. (See also separate comments below on exit stairway remoteness.)

Another example—more-significantly within the section 1.4 of Chapter 1 titled “EVACUATION AND EMERGENCY RESPONSE”—follows the statement (at page 19) that “NIST is interested in determining what factors related to normal building and fire safety considerations, if any, could have saved additional WTC occupant lives on September 11, 2001, or could have minimized the loss of life among the ranks of first responders. This is being accomplished by addressing the following key questions related to occupant behavior, evacuation, and emergency response.” The sixth of these questions is “How did building design features affect egress and emergency access?” Where is the detail on egress comparable to that provided in other sections of the Chapter? Why is the specific, major issue of exit stairway remoteness not even mentioned as a key factor? Why is the specific, major issue of exit stairway enclosure robustness also not mentioned as a related key factor? Notably, other very important, indeed essential information about the egress system—the widths of the three exit stairways and information on where they discharged—is effectively buried in Appendix N, page O-7 under the heading, “O.3.4 Evacuation Experience on September 11, 2001.” A word search of all of the likely documents for provision of this important information reveals that this is the only place it is provided. Other essential egress-related information about the buildings is even more effectively buried, if indeed it exists at all in the Progress Report. For example, where is the information on the size of the WTC floor areas, essential information for estimating the occupant load that codes use to design means of egress as well as information needed for other important aspects of NIST’s investigation? How much of the floor area is available for office occupancy on the various floors (taking into account the varying areas taken up by service shafts, stairways, elevators, washrooms and other spaces in the cores)? From information available to this reviewer from outside the Progress Report (namely a floor plan of floors 84-86), it is known that the towers had nominal plan dimensions (at approximately the line of windows) of 207 feet by 207 feet and the core areas had maximum dimensions of about 133 feet by 86 feet. Thus the overall area of each floor was about 43,000 sq ft and the minimum area available for offices on each floor, and clear of columns, was about 30,000 sq ft. Office “occupant load,” as the building codes use that term, then would be at least 300 people per floor. (See additional

discussion below about occupant load and estimates of occupancy.) Where in the Progress Report—in relation to means of egress—is this information provided? Note, the three exit stairways occupied about 280 and 223 sq ft each (for the one wider and two narrower stairways) for a total area of exit stairways of 726 sq ft or 1.7 percent of the overall floor area per story.

Chapter 1 then goes on to state (at page 20) that, “NIST is using multiple sources of data to investigate occupant behavior, evacuation, and emergency response.” But the sources, while commendably including occupant survey techniques, do not include basic documentation of what form the means of egress system took—including geometric and construction details on remoteness and robustness. Examination of design documents would have identified exactly where the exit stairways were located at various levels and how this related to building code requirements. Informal examination (by this reviewer) of one floor plan (for floors 84-86), suggests that the remoteness rule of the NYC Building Code was not even met and this NYC rule was less stringent than found in some other building codes. (See more detailed discussion below.)

On page 21 of Chapter 1, a potentially very important finding is noted:

*“**Finding 2.4:** About 6 percent of the surviving occupants reported a pre-existing limitation to their mobility. These limitations included obesity, heart condition, needing assistance to walk, pregnancy, asthma, being elderly, chronic condition, recent surgery or injury, and other.*

Given that this estimate is twice the estimate made by Pauls three decades earlier for evacuations of much smaller (27 stories or less) office buildings in Canada, we really need a better understanding of the extent to which limitations to mobility are growing due to decreased fitness generally of Americans today as well as the effects of number of stories of stairs traversed in the WTC evacuation affected occupants’ reporting of mobility limitations.

**Evacuation Flow and Speed.** On page 22 of Chapter 1:

*“**Finding 2.8:** . . . the overall evacuation rate in WTC 2 (108 survivors per min) was about 50 percent faster than that in WTC 1 (73 survivors per min). Functioning elevators allowed many survivors to evacuate WTC 2 prior to aircraft impact. . . . most of those in WTC 1 . . . could only use the stairways. . . .*

*• During the last 20 min before each building collapsed, the evacuation rate in both buildings had slowed considerably to about one-fifth the immediately prior evacuation rate. This suggests that for those seeking and able to reach and use undamaged exits and stairways, the egress capacity (number and width of exits and stairways) was adequate to accommodate survivors.”*

This finding really needs expanding, some substantiating detail and discussion. For example, what were the flows from Tower 1 during the period prior to 20 minutes before its collapse; what was the flow during the last 20 minutes? Would it be correct to say that the flow prior to this 20-minute mark was about 100 persons per minute or was it much higher? Using an empirically derived graph (Figure 4 in the *SFPE Handbook of Fire Protection Engineering Chapter* on “Movement of People”) for flow prediction—but based on evacuation populations, per effective stair width, much smaller than in the

WTC, the total per-minute flows from all three of the exit stairways in Tower 1 could have averaged about 200 persons per minute or a bit higher, assuming no counter flow and a regular, near optimum flow generally. (This is based on the three exit stairways providing, in total, 2.7 meters of effective stairway width.) Further potential insight on this comes from the study by the University of Greenwich team analyzing first-person accounts and estimating, from these, the speeds of evacuees down the WTC stairways. Those estimates suggest speeds ranged between 1.41 and 2.15 stories per minute for Tower 1. With the WTC stairways estimated (by this reviewer using the floor plan for the core area of floors 84 to 86) to have travel distances per typical story of average about 35 to 45 feet (with the upper limit being for evacuees forced to the outer edges of the stairway to allow ascending first responders up the inner part of the stairway), the estimated speed range for WTC would be about 50 to 100 feet per minute or 0.25 to 0.50 meter per second. These speeds are much lower than those suggested, in the *SFPE Handbook*, for crowd movement down stairs where the range is 95 to 150 feet per minute. All of this suggests that, for some unknown reasons, the evacuee flows on the Tower 1 stairs were only about one half of what they could have been.

This raises yet more questions about the NIST estimate of a total evacuation time of about 4 hours, stated in Finding 2.10 for a “full capacity evacuation of each WTC tower with 25,000 people.” Given this reviewer’s understanding of evacuation down office building stairways, NIST’s statement following this prediction should be treated cautiously, “*To achieve a significantly faster total evacuation at full capacity would have required increases in egress capacity (number and width of exits and stairways).*” This is not to say that additional stairway width—and egress capacity—would not be beneficial. For one thing, all of the WTC’s stairways should have been the width of stairway B, about 56 inches in nominal width, their spatial separation (remoteness) should have been significantly increased and, adding one or more stairways would be a good idea, given the likelihood of complete evacuation—*experienced (three times) in the relatively brief, three-decade life of the WTC*. Note that, according to the effective-width model (described in the *SFPE Handbook*), simply making all three of the stairs 56 inches wide, would have improved potential egress flow by a factor of 1.22 and use of a better step geometry, with a riser – tread-depth of 6.8 – 11 inches (rather than the supplied 7.5 – 9.5) would have added some egress flow performance while making the stairway easier and safer to use. The exit stairway area per floor, with only the width and step geometry improvements, would be then increased by a factor of 1.16 (1.32 if the one landing per story were enlarged by 23 sq ft to permit an area of refuge for two wheelchairs per stairway per story). Thus, improving exit stairway width and step geometry would be cost effective relative to improved egress flow potential alone. Hopefully, this kind of detail will be covered in NIST’s draft final report—with recommendations for improvements to means of egress that can actually be fed into the building code revision process as well as guidance to owners, designers, developers and builders.

Complicating the foregoing calculations was absence, in NIST’s Progress Report, of stairway dimensions that would permit more-accurate calculation of travel distance per typical story of travel on the stairs and landings. The authors of the Greenwich paper apparently estimated this at about 31 feet per story, somewhat less than this reviewer’s estimate of 35 to 45 feet per story. It is possible that the Greenwich estimate was based on the horizontal component of speed only whereas this reviewer, following long practice in his evacuation studies, used distance along the stair flight slope plus a horizontal semi-

circular path (or a rectangular path in the case of people being forced to the outside) on each landing.

Project 7, Occupant Behavior, Egress, and Emergency Communications included the task of “evaluating the performance of the evacuation system on September 11, 2001” (page 129) which is identified, in part, as Task 3 (page 130). This includes “physical aspects of building egress components, such as stairs (width, number, location, vertical continuity).” Egress features, including remoteness and protection of egress stairways,” are mentioned (on page 132) but there is no discussion of these features in the WTC relative to the evacuation possibilities on 9/11. Indeed, contrast the level of detail in this review’s foregoing paragraphs with the level of detail provided on the means of egress system and its performance in the Progress Report.

Finding 3.20 (on page 38 of Chapter 1) fails to recognize the available, albeit inadequate and dated, research and technology on means of egress design and performance. The authors should examine, for example, the “Movement of People” chapter of the *SFPE Handbook of Fire Protection Engineering* and the references it cites. There is significantly more understanding and technology that can be applied to prediction of egress system performance than implied by the superficial treatment of this topic in the Progress Report.

Finding 3.21 needs to very critical review as it is questionable that the survey questions (and perhaps staff/consultant orientation) were even appropriate for investigating the detailed effect of first-responder counterflow—to the extent possibly involved in the WTC exits—on evacuee movement. In such a critical review, we need to consider the extent to which relatively low flows (and speeds) were a cause or an effect. In other words, counterflow was not a big issue because evacuee flows and speeds were already relatively low. Alternatively, evacuee flows and speeds were reduced partly because of counterflow. Where, in the survey instruments, are the specific questions addressing counterflow?

## **Chapter 2**

On page 43, it is boldly stated that “NIST has received all of the essential information it needs for the WTC investigation.” Is this genuinely true? The limited coverage of means of egress and evacuation in the Progress Report implies otherwise. Why is there not better documentation of the means of egress system provided in the Progress Report—at least to the extent that other topics are addressed in the Progress Report? Will NIST provide access to other investigators and researchers to the complete materials it claims to have so that a better job can be done to assess what, when, who, where, why and why not questions? Others may, for example, be more inclined to speak with journalists to gain direct information about what is in their databases, to augment the information NIST researchers have examined and analyzed.

Regarding the account of how the Port Authority innovated with aspects of the design and construction of the WTC, one should critically ask why it did not do so with the means of egress system. Surely the largest, tallest office buildings warranted a much more creative, skilled consideration of means of egress. The exit stairways, with the

exception of the wider width of Stairway B, were of mediocre quality relative to egress performance and were, in this reviewer's professional opinion, clearly deficient in terms of their remoteness and robustness of enclosing construction.

With the foregoing in mind, a remarkable section of the chapter is found at page 59 regarding changes made to the 1938 code, partly to give more flexibility to WTC designers and others: "Some of the advantages of the new draft code were noted to be the following (Levy 1965):

- Fire towers could be eliminated;
- Provisions for exit stairs were more 'lenient;' and
- Criteria for partition weights were more 'realistic'."

On page 60, one aspect of the more "lenient" exit stairs—the determination of exit stair width—is identified from a one-page document identified as "Changes to Building to Conform to 'New' New York City Building Code," dated 2/15/67:"

2. Number of stairs reduced from 6 to 3. (Old plans had 5 stairs at 3'-8" and 1 stair at 4'-8" for a total population of 390. New plans have 2 stairs at 3'-8" and 1 stair at 4'-8" allowing a population of 390.)

On page 132 is the following statement on the database for the occupant behavior topic: "The database can be obtained electronically at <http://wtc.nist.gov>." Where exactly is the web site for the database? A more specific address should be provided as neither the database nor an obvious link was found at the address shown.

On page 135 there is a tantalizing, unclear clue as to how NIST staff estimated the number of occupants in the building at the time of the attack on September 11<sup>th</sup> but, at least for this reviewer, there is the unanswered question, what is meant by "known eligibility rates for a projection of the survivors?"

"Using the known eligibility rates allows for a projection of the survivors of WTC 1 and WTC 2 present in the building at 8:46 a.m. on September 11, 2001. The analysis indicates that WTC 1 had approximately  $7,500 \pm 750$  surviving occupants, while WTC 2 had approximately  $7,900 \pm 900$  surviving occupants. Thus, the total population of survivors from both towers was  $15,400 \pm 1,200$ . Table 2-9 summarizes the projection of population of WTC 1 and WTC 2 on September 11, 2001. Pending resolution of decedent locations, the total building population at the time of the first airplane impact was  $17,400 \pm 1,200$ , calculated using the building decedent locations reported by Cauchon."

Throughout Chapter Two's treatment of the occupant behavior and evacuation portion of the investigation, it is clear that much remains to be done with the analysis of information. Will the public be provided with another progress report so there is a much improved basis for wider study of the findings before public comment is requested on the report with recommendations? As has been noted in these comments, the delay in publishing findings and other information on the means of egress system is especially troubling partly because this work was presumably not delayed because of the analysis needed of survey data. Something more troubling may be at the heart of this deficiency—something this



reviewer believes relates to long-term short shrift NIST has given to means of egress generally.

### **Chapter 3**

Chapter 3, WTC R&D program, identifies four areas of research including “Improved Emergency Egress and Access.” Under this heading is described a poorly defined problem and the promise of future progress: “behavior of people in an emergency situation has been altered in unpredictable ways by the events of 9/11. Current egress models may be inappropriate and/or insufficient for the design and placement of doors and stairways and the control of elevator movement. Behavioral and engineering studies are being conducted, drawing on experts in academia and elsewhere, to enable the development of simulation tools that better capture the movement of people within a building under fire and other emergency situations.” The focus on simulation tools is somewhat premature (in this reviewer’s opinion) because the egress field—especially under NIST’s leadership in the USA—has been inadequately addressed for decades and there is now a large backlog of data collection that should be done before there is much more attention to models. “Garbage in leads to garbage out.” For example, we need more and better data on how evacuees deal with doors, in terms of deference behavior when people from floors try to merge with people already on exit stairs and in terms of appropriate matching of various doorway widths and stairway widths. Right now our best estimate of the latter is, respectively, a 2-to-3 or 3-to-4 ratio of widths for exit discharge doorways and exit stairway widths. Given the relative sophistication of other aspects of the NIST WTC study, we should be able to do better than that. We also need to get a better idea of how the increasing individual body weight and decreasing fitness of the US population should be addressed in egress and life safety generally in buildings. (The is addressed in a current public proposal and public comment, by Pauls, to NFPA, relative to changes to minimum exit stairway width required by NFPA 101 and NFPA 5000.)

Mention is made (on page 155) of a workshop on building occupant movement during fire emergencies, arranged by NIST in conjunction with United Technologies Research Center in early June 2004. Unfortunately, the organizers did not take into account, when scheduling the two-day meeting, that it conflicted with the 7<sup>th</sup> World Conference on Injury Prevention and Safety Promotion in Vienna. The latter had been scheduled years before; the NIST workshop was scheduled weeks before. As a result, key experts who have worked in the egress field for decades—and had met with NIST staff in January 2004 to encourage such a meeting—were unable to participate in the workshop. NIST has got to do better than this if it is really serious about being a leader in the egress field. Also, for those unable to get to the workshop, where is the documentation on the meeting including copies of presentations and synopses of discussions and recommendations coming out of the meeting? How many of the questions noted in this comment were raised, let alone adequately addressed, in the Workshop?

### **Progress Report Appendices**

Moving now to the Appendices of the Progress Report, Appendix A is titled an “Interim Report on the Analysis of Building and Fire Codes and Practices.” Is there really going to be an expansion or revision of this for the report promised for December 2004? If so,

there should be improvements made in the coverage of means of egress issues. Notably, after a somewhat academic, but superficial treatment of means of egress generally, the report's section "**A.5 PRELIMINARY FINDINGS**" (on page A-29) has only two sentences on "**Provisions Related to Egress**" (page A-32). They are: "The 1968 New York City Building Code contained similar requirements to the other contemporaneous codes, which were compared, for the number and capacity of exits and stairs and for the design occupant load. The New York City Code permitted scissor stairs (two stairs in one shaft separated by a fire-rated partition) with doors located at least 15 ft apart, whereas other building codes prohibited scissor stairs." Nowhere in this appendix is there any discussion of the ironic feature of the WTC, with exit stairways not discharging directly to the outdoors, while possibly a code violation, actually being a virtue during the evacuation on September 11, 2001. Final egress, to the outdoors, was best done as far away from the towers as possible, given the debris and falling bodies. Related to this, apparently nowhere in the treatment of the evacuation is there a much-needed treatment of the final portions of the egress route, between the exit stairs and the streets outside. Success with this was crucial to the relatively successful evacuation of those able to get to the usable portions of the exit stairways. Exactly how did the building and those assisting evacuees function for this? What lessons might this eventually hold for other large buildings in highly developed urban contexts such as New York? Note this apparent omission, along with the superficial treatment of egress movement generally, reflects the apparent lack of experience of NIST staff, most of its official advisors and consultants/contractors with means of egress systems, their performance and their regulation. Human behavior consists of much more than things like initial perceptions of the situation and delays in initiation of egress.

This brings us to Appendices N and O which reflect the bias of influential NIST researchers to relatively narrow aspects of human behavior as just noted above. Why did NIST staff not address, either proactively or with the production of the Progress Report, the treatment of means of egress issues in the WTC? Knowing some of the key staff and consultants/contractors for some time, multiple reasons for the superficiality and bias are known, by this reviewer, beyond those noted in this report. They should all be addressed *before* NIST produces its draft final report in December 2004—especially if NIST wants to maintain its reputation, financial support and role in National Construction Safety Team Act investigations.

Some of the inadequacies in Appendix N are addressed in the appendix to these comments. Before producing its December 2004 report, NIST should carefully consider the parallel analysis of "first-person accounts" done by researchers at the University of Greenwich (and this should go beyond the published report on the UK study available to this reviewer). If nothing else, NIST's consideration should address bias issues in the analysis of the accounts. Also, to what extent are quantitative insights—such as estimates of stairway descent speeds—derivable from the accounts? How can account quality issues be addressed, especially as there is a tremendous range of journalistic competence reflected in the various contexts in which the accounts are found? The UK researchers tried to address this. The NIST researchers apparently did not, at least as reflected in Appendix N. This appears evident to this reviewer who was sufficiently concerned about such quality issues—and NIST's consultants' handling of this—to excerpt portions of one reported account, along with a small investigation into the chain of evidence, in a paper presented at the recent 3<sup>rd</sup> International Symposium on Human

Behaviour in Fires; this is quoted in the appendix to this comment.

Appendix O of the Progress Report is among the least informative of the interim reports provided. Of course, some of this is because of the delayed conduct of the telephone interviews and their analysis. (Compare its level of detail with the extraordinary detail provided in Appendix C with the comparably incomplete treatment of the aircraft impact.) But there are other aspects of the Occupant Behavior investigation that, even if completed, are inadequately addressed. For example, why was there no Appendix provided—beyond N and O—dealing generally with the first two major topics in Project 7? These are identified as follows (in Table P-1, page xxviii of the Preface): “Occupant Behavior, Egress, and Emergency Communications” which has the Project Purpose: “Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.” Where, for example, is a discussion of findings from the focus groups?

## **Remoteness of Exit Stairways: A Neglected, But Important Topic**

In the Executive Summary the topic of remoteness of exit stairways is referred to only once—and then only as one element of a list of egress considerations—on page xlvii (49) of the Executive Summary. There is no discussion, as there is regarding other major issues, about the major role that might have been played by inadequate remoteness of the three exit stairways from each other which resulted in their simultaneous loss upon aircraft impact (with the short-term exception of one stairway in Tower 2).

Remoteness is referred to only twice in Chapter 1, Interim Findings and Accomplishments, and then only as one element of a list of egress considerations (on page 38) and in relation to a mostly irrelevant discussion of scissors stairs (on page 39)—***but not in relation to the blockage or loss occurring upon aircraft impact.*** This issue relates especially to NIST’s objective 2. “To determine why the loss of life and injuries were so low or so high depending on location, including technical aspects of fire protection, occupant behavior, evacuation, and emergency response.” (Presumably the design and construction of means of egress—for which exit remoteness is a key factor—is subsumed under the label “fire protection” but would be better identified separately as “means of egress” because means of egress have to operate under a variety of normal and emergency conditions having little to do with fire.)

At page 21 of Chapter 1, the NIST staff assumption is noted that 20 percent of the people who died may have been alive at the time of collapse but this estimate includes “none of the people at or above the floors of impact who may have been alive.” Using NIST’s demographic estimates, above the level of aircraft impact, an estimated 2,083 occupants in both towers died due to the initial impacts, the resulting fires or the final collapses. Had one or more exit stairways survived the aircraft impact—due to greater remoteness from each other and greater robustness of the exit enclosures, some of these people might have survived by escaping through the impact levels. Evidence for this comes from the temporary availability of one of the exit stairways—jogging outward from the center of

the core at about the impact level—in Tower 2 which permitted several people to escape. Thus exit stairway remoteness did matter, especially with the off-center, aircraft impact into Tower 2.

As noted in the general section above, informal examination of two drawings of one floor plan, for floors 84 to 86 (the only one available to this reviewer), suggests that the remoteness rule of the NYC Building Code was not even met and the NYC Code rule was less stringent than found in some other building codes. Ironically, although the NIST report has some very useful figures to illustrate other aspects of the investigation (such as perimeter column damage), where are figures with representative floor plans showing the core area and the location (and designation—A, B and C) of the three exit stairways? Judging from the floor plan of floors 84 to 86, the exit stairways were much closer together than the available core options would appear to permit. Relative to the roughly 200-foot by 200-foot floor dimensions—and core dimensions of 86 by 183 feet—the three exit stairways were effectively within an area 44 feet by 54 feet with maximum, direct-line distances between entrance doors of only 45 feet. (Relative to modern code requirements for remoteness, the 45 feet can be compared with a diagonal dimension of the floor of 285 feet; this ratio is 0.16 compared to a modern criterion of 0.5 if unsprinklered and 0.33 if sprinklered.) Thus the three exit stairways clearly appeared not to be “as remote from each other as practicable,” the reported NYC Building Code requirement at the time of WTC design. (See full quote and further discussion of this issue two paragraphs below.) Reportedly, the NIST staff have *all* of the necessary building plans to complete their work; where is their assessment of this important issue? This should have been dealt with in the Progress Report.

Chapter 2 of the Interim NIST report includes the analysis of building and fire codes and practices (Project 1). Task 2 and Appendix A include documentation of the design and construction of the fire protection and egress systems and Task 4 consists of comparisons among codes.

Significantly, on the matter of exit stairway remoteness, the report does not state a specific requirement of either the 1938 or 1968 NYC Building Code. It merely states, “Codes of the time required that multiple stairs be located ‘as remote from each other as practicable.’ NYC permits scissor stairs, and the code requires the exit doors to be at least 15 ft apart. Local Law 16 (1984) first imposed a remoteness requirement of 30 ft or one-third the maximum travel distance of the floor (whichever is greater), which was not retroactive, so it did not apply to WTC 1 and WTC 2 but did apply to WTC 7.” Incidentally, this reviewer’s criticisms of the WTC’s exit stairway remoteness, and of remoteness requirements generally, were made publicly in New York City in 1992, first in the Department of Buildings forum in August and then in a major presentation to the Fire Safety Directors Association of Greater New York in November. Detailed PowerPoint presentations from both are available on request and were also left with meeting organizers in each case. Accepting for the moment the lack of logic in the NYC code rule—with its tie to travel distance limited to 200 feet, the minimum distance between exit doors should have been at least 67 feet rather than the 45 feet estimated on floors 84-86 for example, as discussed in the prior paragraph. Where in the Progress Report is there an analysis even comparable to the one presented in this comment on this issue of inadequate remoteness relative to NYC code or other code criteria?

Project 2, Structural Analysis, does not specifically mention the damage to exit stairway enclosures in its discussion of aircraft impact damage (page 73). The more-dense, 9,000-pound jet engines would have caused the most intense initial damage but there were only two of them per jet and there were three exit stairways partly protected by major columns. There is apparently no NIST analysis reported on how extensively the stairways would have been damaged and how this would change if they were at more-remote locations. NIST's emphasis is clearly on the main structural elements and their details, not the critical, highly vulnerable vertical egress routes.

Appendix A, Interim Report on the Analysis of Building and Fire Codes and Practices, includes a somewhat superficial, incomplete treatment of code requirements for means of egress. Notably, there is absolutely no mention of exit stairway remoteness, a major factor in the simultaneous loss of all the WTC towers' three exit stairways at the point of aircraft impact. *This is an inexcusable, unacceptable omission.*

## **Appendix: Comment about Appendix N, Interim Report on Analysis of First-Person Accounts from Survivors of the WTC Evacuation on September 11, 2001**

This comment consists mostly of an excerpt (reproduced below with indented margins) from the recent paper by Jake Pauls and Phillip Wearne, "Comparing Journalism, Conventional Research and Legal Proceedings as Sources of Insights into Human Behaviour in Disasters in Buildings," Proceedings of 3<sup>rd</sup> International Symposium on Human Behaviour in Fires, 2004, pp. 193-202.

Also in the Proceedings of the Symposium are two papers, each reporting on analyses of "first person accounts" of the WTC evacuation; the first is by the authors of NIST's study reported in Appendix N; the second is from the University of Greenwich Fire Safety Engineering Group. Respectively they are: **ACCOUNT ANALYSIS OF WTC SURVIVORS** by Guylène Proulx, National Research Council of Canada and Rita F. Fahy, National Fire Protection Association; **AN ANALYSIS OF HUMAN BEHAVIOUR DURING THE WTC DISASTER OF 11 SEPTEMBER 2001 BASED ON PUBLISHED SURVIVOR ACCOUNTS** by S.J. Blake, E.R. Galea, H. Westeng and A.J.P. Dixon. The latter paper (on a study funded by United Kingdom Office of the Deputy Prime Minister, the agency responsible for the UK building regulations) is more detailed, including for example, estimates of speeds of stair descent for each tower as well as consideration of reliability of the data from the accounts examined. In neither case did the researchers confer directly with the journalists responsible for the published accounts. This omission—which missed access to relatively good data sets—is referred to below as a failure of researchers to "collaborate" with journalists. Beyond the resulting deficiencies in research, one needs to ask why NIST did not work more closely with journalists in its more powerful role as *the* federally mandated *investigator* into the World Trade Center buildings disaster. At least NIST could have reported on its success (or lack of it) in requesting that journalists share their databases of original interviews, as well as interview protocols, with NIST investigators *for the greater public good*. This reviewer's discussion with the Providence Journal staff member responsible for its database on the Station Club Fire evacuation revealed that, reportedly, NIST's first

reaction to being *offered* the complete database was negative, apparently out of NIST staff concern for the absence of any Institutional Review Board (IRB) approval for the very extensive interviewing done by Providence Journal staff. The red herring of IRB approval, especially for *investigations—as opposed to academic research*, is addressed in the paper, by Pauls and Wearne, from which the following discussion of the NIST analysis of first-person accounts is quoted.

It is important that conventional researchers collaborate in a meaningful fashion with journalists rather than merely drawing on the early insights of media accounts of what happened in particular disasters. For example, it appears that the NIST-funded analysis of first-person accounts (from journalists' stories for example) from the World Trade Center disaster did not involve detailed discussions between the journalists and the researchers. Only a small fraction of the data amassed for stories in the *New York Times*, *USA Today* or *Providence Journal* after the World Trade Center and Station Club disasters was published—an estimated 25 percent in the case of the *Providence Journal's* database (according to discussion with the database developer, Paul Parker). Ironically, the published accounts tend to focus on individual behaviours and experiences while they de-emphasize the fact that these might have been documented—but *not published*—for some larger number of persons. Thus researcher comments about generalizability of media accounts do not fairly address what could be drawn from the journalists' databases—if the *conventional researchers and the journalists worked collaboratively*.

It is curious that there appears to be a kind of schizophrenia in the fascinating analysis performed by researchers at the National Fire Protection Association (NFPA) and the National Research Council of Canada (NRCC) that was released publicly in June 2004 as the “Interim Report on Analysis of First-Person Accounts from Survivors of the WTC Evacuation on September 11, 2001.” The authors—not identified in the “Interim Report” but known to be Rita Fahy of NFPA and Guylene Proulx of NRCC—expressed opposition, in October 2001, to interviews being done of survivors of the WTC disaster but, in this analysis of journalists' interviews plus otherwise-recorded and publicized “first-person” accounts, they embrace them as valuable for their insights if not their generalizability which is only first referred to on page N-9 of the report: “Results presented in this report should not be generalized to all occupants of the two towers on September 11, 2001.” This appears four pages after the authors comment:

Despite the drawbacks of using media sources for the basis of research, however, some of the accounts contained such a high level of detail, particularly the ones written by survivors themselves, they provided justification for the analysis of this information. It should also be stressed that these media accounts are the only documented descriptions of the WTC evacuation and immediate reactions of the survivors, as no research has been conducted or published 2

years after the events, regarding human behavior surrounding the events of September 11, 2001. Since documenting human behavior is time sensitive and considerable time has passed since the event, it may be said that these initial media accounts may hold significant detailed and accurate information that may only be available in these accounts.

Curiously, and sadly, they apparently took the published accounts at face value without discussing, for example—*directly with the journalists*—the interviewing process and database resources used by journalists, let alone all of the possibly less-skilled and less-reliable people who produced the various accounts. The “Interim Report” does not even present an analysis of what specific resources were used beyond noting they included “television, radio, newspapers, magazines, websites, books and special media programs” as well as “personal websites and e-mails written by survivors themselves.” Without exploring exactly how—and how diligently—these accounts were elicited, recorded and published, we have a fascinating analysis that is weak on foundation and thus relevance.

The relatively few citations (in the report’s Reference section) to the specific sources are revealing as they raise questions that need answering about the relative quality of the means by which first-person narratives came to be public. It would be helpful to know the extent to which we are dealing with true “first-person” accounts as opposed to hearsay. (Incidentally, in courts of law, expert witnesses—unlike fact witnesses—are permitted to use hearsay in presenting their opinions; thus we need to inquire into the degree of expertise employed here, including the authors’ apparent failure to delve more directly into the journalistic research process.)

A case in point is found on page N-19 of the Interim Report: “One survivor from the 70th floor of WTC 2 said she and her co-workers walked down to the 59th floor and took an elevator to the 44th floor, when at that point, another plane hit their tower and then there was a mad scramble down the stairs with people pushing, shoving and yelling (Black 2001).” “Black” refers to Barbara Black, editor of *Concordia’s Thursday Report*, a bi-weekly community newspaper at Concordia University in Montreal, Canada. For the November 22, 2001, issue she put together a story, “How the telephone linked an anxious family on Sept. 11,” which was “based on a phone log” compiled by the mother of a Concordia University graduate who, along with her husband, were in separate buildings of the World Trade Center on 9-11. The phone log includes numerous calls to/from four countries as the couple went through the evacuation process while, apparently desperately trying to communicate with each other as cell phones proved unreliable. As fascinating as this is as a historical record of some of the human dramas occurring that morning, we need to carefully question the use of such material in a report as part of the NIST research, especially the use in coding and presenting

findings about certain occupants' behaviour. How reliable is the chain of reporting here? Exactly who characterized the evacuees' behaviour as "pushing shoving and yelling?" What are the true answers here to What, Who, Where, When and Why? How many of the 435 individuals' accounts, analyzed in the study, came from this kind of reporting process? How many came from more-careful work by experienced journalists such as those acknowledged at the end of this paper? How many came from dubious Internet sites or E-mails?

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## II.

**J. G. Quintiere: review of NIST WTC Investigation. The following constitutes the NIST projects designed to reach the objective of the Investigation.**

September 11, 2004

**NIST Projects: Federal building and fire safety investigation of the WTC disaster**

**Project No./Technical Area /Project Purpose**

1. Analysis of Building and Fire Codes and Practices
  - a. Document and analyze the code provisions, procedures, and practices used in the design, construction, operation, and maintenance of the structural, passive fire protection, and emergency access and evacuation systems of the WTC 1, 2, and 7.
2. Baseline Structural Performance and Aircraft Impact Damage Analysis
  - a. Analyze the baseline performance of WTC 1 and 2 under design, service, and abnormal loads, and aircraft impact damage on the structural, fire protection, and egress systems.
3. Mechanical and Metallurgical Analysis of Structural Steel
  - a. Determine and analyze the mechanical and metallurgical properties
4. Investigation of Active Fire-Protection Systems
  - a. Investigate the performance of the active fire protection systems in WTC 1, 2, and 7 and their role in fire control, emergency response, and fate of occupants and responders.
5. Reconstruction of Thermal and Tenability Environment
  - a. Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.

6. Structural Fire Response and Collapse Analysis
  - a. Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of open-web steel joists, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.
7. Occupant Behavior, Egress, and Emergency Communications
  - a. Analyze the behavior and fate of occupants and responders, both those who survived and those who did not, and the performance of the evacuation system.
8. Fire Service Technologies and Guidelines
  - a. Building on work done by the Fire Department of New York and McKinsey & Company, document what happened during the response by the fire services to the WTC attacks until the collapse of WTC 7;
  - b. identify issues that need to be addressed in changes to practice, standards, and codes;
  - c. identify alternative practices and/or technologies that may address these issues; and
  - d. identify research and development needs that advance the safety of the fire service in responding to massive fires in tall buildings.

**The NIST investigation objectives are:**

1. To determine (a) why and how the WTC 1 and WTC 2 collapsed following the initial impact of the aircraft, and (b) why and how the 47-story WTC 7 collapsed.
2. To determine why the loss of life and injuries were so low or so high depending on location, including technical aspects of fire protection, occupant behavior, evacuation, and emergency response.
3. To determine the procedures and practices which were used in the design, construction, operation, and maintenance of the WTC buildings.
4. To identify, as specifically as possible, areas in national building and fire codes, standards, and practices that warrant revision.

Among the **specific questions that NIST is investigating** within the above four objectives are the following:

- How and why did WTC 1 stand nearly twice as long as WTC 2 before collapsing (103 min versus 56 min), though they were hit by virtually identical aircraft?
- What factors related to normal building and fire safety considerations not unique to the terrorist attacks of September 11, 2001, if any, could have delayed or prevented the collapse of the WTC towers?
- Would the undamaged WTC towers have remained standing in a normal major building fire?
- What factors related to normal building and fire safety considerations, if any, could have saved additional WTC occupant lives or could have minimized the loss of life among the ranks of first responders on September 11, 2001?
- How well did the procedures and practices used in the design, construction, operation, and maintenance of the WTC buildings conform to accepted national practices, standards, and codes?

I have chosen to evaluate project numbers: 3, 5 & 6 and will utilize the following guidelines in critiquing these projects:

**Issue for the project**

**Approach taken by NIST**

**Questions on the Approach**

**Comments on ability to address objectives**

## **Evaluations of projects 3, 5 & 6:**

### **Project #3 - Mechanical and Metallurgical Analysis of Structural Steel**

Objective: Determine and analyze the mechanical and metallurgical properties

#### **Issue**

NIST has established the mechanical and thermal properties of the steel used in the WTC, and generally has found no remarkable departures from the literature for steel. However, an important aspect of this fire and large fires in general is the temperature reached by the fire, and that achieved by the steel.

#### **NIST approach**

In the December 2003 Public Update it states that part of this task objective is “estimating the maximum temperature reached by available steel” (p.8). In the May 2003 (p. 33) and June 2004 Vol. 1, p. 87), it appears that this objective is being done by examining paint degradation at 250 and 750 C.

#### **Questions**

A common forensic technique for determining the temperature reached by steel in a fire is to microscopically examine the grain size. It has been said that very precise determinations can be made if compared to an unheated similar steel sample. Why has NIST not used this method?

#### **Comments**

The importance of knowing the temperature achieved by the steel on the fire floors is crucial to establishing the cause of the buildings collapse. This is like a thermometer in the building, so its significance cannot be overlooked. The temperature of the fire and the steel are important in determining the time and the nature of the collapse of the buildings. NIST is using computational methods to predict these temperatures. It is incumbent on NIST to use all methods for ascertaining the steel temperatures to achieve confirmation of its predictions.

Also, NIST has steel samples salvaged from the dumpsite, and has said those samples were adequate. NYC made a unilateral decision to remove and sell the steel before the

NIST investigation began. What is the NIST recommendation on how to preserve evidence in future investigations in order to render complete structural and thermal analysis to the debris samples? Was the steel prematurely discarded in the WTC before adequate analysis could occur?

#### **Project #5 - Reconstruction of Thermal and Tenability Environment**

Objective: Reconstruct the time-evolving temperature, thermal environment, and smoke movement in WTC 1, 2, and 7 for use in evaluating the structural performance of the buildings and behavior and fate of occupants and responders.

#### **Issue**

The accuracy of the computer modeling predictions for the fire environment need to be assessed, and their consistency with literature data for fully developed fires and with the factual evidence of the WTC fires needs addressing. A computation of this magnitude is beyond the state of the art for fire modeling, and although NIST and the investigators should be commended for their efforts at pushing the state of the art, they must not solely rely on computer-driven computations for estimating the fire temperatures. They have other sources from which to also draw information on the state of the fire: They include: conducted fire tests, correlations for fully developed fires in the literature, data on window breakage and the fire progress, and people reaction to the fire heat and smoke from potential interviews. Consistency must be assessed between the various sources of information and from alternative, albeit, simpler computational methods.

#### **NIST Approach**

Information about the fire can come from several sources. NIST has extensively examined and compiled the fire behavior and its effect on the building through the correlation of various photographic evidence. This task has been done with excellence it appears, and should offer valuable information. Another source of fire could come from the collection of data from people. This appears to have lagged and it is not clear that anything of value in a timely manner will be reported on the fire and damage effects observed directly by people and ascertained through interviews. In all of the fire predictions NIST has chosen to use its Fire Dynamics Simulator (FDS) as the sole

computational tool. In order to evaluate its accuracy, experiments have been conducted on small features of the WTC office occupancies in order to calibrate and assess the accuracy of the fire predictions. Hence, both the modeling and the experimental data offer information on the WTC fires. As with other aspects of the investigation, NIST appears to be weighting the computational approach as their primary result, especially since that result must be supplied to the structural modelers in order to make their prediction of the building's ability to carry its load.

NIST has approached the validation effort by conducting two series of tests. The first series consisted of a spray fuel fire in a compartment containing structural members. The second involved a larger compartment containing three workstations that NIST decided were representative of the WTC offices. That fuel load is roughly 4 lb/ft<sup>2</sup> (psf) (or about 20 kg/m<sup>2</sup> and 50 MJ/ m<sup>2</sup>), June 2004 Vol. 1, p xxxvii, Vol. 5, J-37.

Series 1 consisted of the following (June 2004 Vol. 5, J-2):

The test compartment consisted of a steel stud frame lined with calcium silicate board. The internal dimensions of the compartment were 3 m high, 7 m deep, and 4 m wide. There were four openings in the west wall through which air entered the room; they totaled 1.75 m<sup>2</sup> (10.8 ft<sup>2</sup>) in area and were located 1 m (3.3 ft) above the floor. There were four openings in the east wall through which heat and combustion products were emitted; they also totaled 1.75 m<sup>2</sup> (10.8 ft<sup>2</sup>) in area and were located 2 m above the floor. In each of the six tests, the four test subjects were a bar, two trusses, and a thin-walled tubular column. Depending on the test, these specimens were either left unprotected or were coated with spray-applied fire protective insulation material, Blaze Shield DC/F. The fibrous insulation was applied by an experienced applicator who took considerable care to apply an even coating of the specified thickness. As such, the insulated test subjects represent a best case in terms of thickness and uniformity. The fires consisted of liquid hydrocarbon fuels sprayed by a two-nozzle spray burner onto a 1 m × 2 m (3.3 ft × 6.6 ft) pan. The fuels were (a) heptanes and (b) a mixture of nominally 60 percent (by mass) heptanes with 40 percent toluene. The latter fuel produced a significantly sootier flame.

Six tests were done. The instrumentation for the tests comprised up to 352 channels of data.

Series 2 consisted of 3 workstations in a large room (June 2004, Vol. 5, J-27):

Six experiments were designed to assess the accuracy with which FDS predicts the fire spread, heat release rate, and thermal environment in a compartment burning multiple workstations in a configuration characteristic of that found in the WTC buildings. In each of these experiments, sets of three workstations were burned in a large compartment (about 11 m x 7 m x 3.4 m high). The challenges to the model included varying the location of the ignition burner (and thus the fire ventilation), adding jet fuel and/or noncombustible material occluding a fraction of the workstations' surfaces, and "rubblizing" the workstations.

NIST performed some additional computations based on FDS. They have early on reported on the smoke dynamics from the building (Rehm et al., IAFSS 2002), and recently on the fireball dynamics (Baum, Comb. Inst., 2004). These are considered somewhat ancillary to the prediction of the fire conditions on the floors that bear directly on the heating of the structure and the effect of the fire on the ultimate collapse. However, the work by Prasad and Baum (Comb. Inst. 2004) on linking the predictions of FDS for the fire with the heating of core columns under different core damage scenarios is very significant. It is the closure of the fire and the structure modeling that is critical to answering the issues pertaining to collapse.

### **Questions**

It is well known that FDS results depend on the grid size and its scaling to the fire conditions. The experiments done by NIST may well serve the credibility and accuracy of using FDS with a grid size of 40 cm, but enough comparison has not been shown between the computations and the experiments. Only about 4 or 5 plots have been presented for comparison in the reports, and they show very good prediction for the fire gas temperatures and heat release rate. Some of NIST's own funded work (Ierardi and Barnett, 2003) have shown that the accuracy of predicting a single fire plume from a 30 cm burner give drastic variations in temperatures with the fire plume for grids of 1.5 to 15 cm. Temperatures within 20 per cent of the experiment results required grids of 1.5 to

5 cm. So it is incumbent on NIST to address this accuracy question completely. They have done 13 experiments with over 300 measuring stations in each test. In the least, NIST needs to demonstrate the ability of FDS to compute all aspects that FDS has in common with these measurements.

The issue of accuracy for computer models is a serious matter when they are to be used as general engineering tools. The literature is filled with data and correlations for fully develop fires. NIST should at least demonstrate how its approach using FDS compares to these other empirical approaches in the literature. Japan uses one of these empirical approaches as a design method in regulations, and the SFPE has just completed a guide on the prediction of fire conditions for structural considerations. It has been said that the full WTC floor simulation agree with the phenomenon observed by (I. Thomas et al.) in which the fire moves about the compartment seeking air. Can FDS predict the data of Thomas? These questions are broader than the effort that has gone into the WTC simulation, and therefore it would be important for NIST to examine FDS in light of its validation needs. Moreover, FDS is using a charring model to compute the burning rate and flame spread on the workstations, and NIST should state the accuracy of using FDS for the prediction of flame spread on charring materials. Boeing would not take the use of CFD models in its aircraft design lightly, and neither should those assessing fire behavior, especially from NIST.

The fuel load selected in the representative experiments and the modeling raises some questions. NIST is using roughly 4 psf, and a floor burns for an average of about 1 hour (Key Findings of NIST's June 2004 Progress Report...). This selection of loading is critical to establishing the burning time, crucial to predicting the impact of fire on the structure. The literature (Robertson and Gross, ASTM STP 464, 1970) suggests an average office load of 18.4 psf, ranging from 7 to 43 psf according to surveys. Why is the WTC representative office so low? This needs examining and supportive data.

In an investigation where information comes in different forms, the final analysis must show that the information pieces are consistent. NIST has observational information, hopefully people information, experimental test information, and the FDS simulations. These must be shown to be consistent.



Ultimately FED results must be linked to a structural model. Prasad and Baum (C.I. 2004) have attempted this for the heating of the core columns. They show that simplifications need to be made in representing the FDS temperature spatial distributions in order to better interface with the structural heating model. Their approach has demonstrated the needed closure of the fire and structural heating. However, they have not considered the vulnerable floor assembly in their calculations. This will need to be added to fully assess the role of the fire on the complete structure. NIST has not made clear how the fire and structural computations will come together, particularly since the structural modeling is being done under contract. We would like to see NIST speak to the accuracy and issues related to the modeling of the fire and structure together. Since NIST has test data on the heating of insulated structural members in their fire tests, some comparisons, at least, need to be presented for these simpler fire scenarios.

Can NIST successfully modeling the 1975 WTC fire (June 2004, Vol. 4, G-1) that did extensive damage to a floor? This fire prompted the use of sprinklers, and local structural damage occurred. Since the damage and extent of the fire was known, it could be a useful benchmark for NIST to compare their simulations.

### **Comments**

The fire computations are perhaps the most important determination since its heating impact and its duration determine the ultimate temperature of the protected steel. The heat transfer by conduction into the insulation and the steel is trivial by comparison. Also when it realized that failure in furnace testing of structures is often based on steel temperature, and temperature strongly affects the strength of steel, e.g. the modulus of elasticity is reduced by 50 % when steel attains about 600 C. Since the modulus is directly related to the critical load to cause buckling, the buckling of elements in compression can occur more easily at elevated temperatures. The ability of the fire modeling to relate to the structural heating model is very import step in this investigation. NIST should make this step as transparent as possible in order to judge its conclusions. FDS will yield a spatial and time varying temperature throughout a floor. Its accuracy needs to be supported at this level of sophistication. Alternative estimates on the level of temperature and its duration might need to be couched in simpler forms for the best structural analysis to be produced. It might serve just as well to specify uniform

temperature in a range. The duration will depend on the fuel load, and it has been pointed out that the NIST selected load is very low compared to office load surveys. Some variation of uncertainty must be considered here.

Finally, it appears almost foolish to have received \$16 million for the investigation and to not have conducted a test more representative of a WTC floor. A quarter of a floor could have been tested for fire and the heating of the structure. It would only involve a plan space at 100 x 100 feet. This could have settled many issues. Especially when it is realized that no experimental results exist for compartments with small ratios of height to their lateral dimension as 1/20 in the WTC. The smallest has been 1/4 in the well known CIB studies, and those results should be examined by NIST for their applicability. However, the interaction of air from the perimeter and fuel within the compartment need to be examined under these conditions by an experiment, to at least see if FDS is qualitatively correct. Moreover, it is known that in large fire plumes that smoke can trap radiation and drive the core fire temperatures to 1300 C and more. This can happen at fires of 30 ft in diameter, so the question must be raised if this might apply to the WTC with lateral floor dimensions of 200 ft.

## **Project #6 - Structural Fire Response and Collapse Analysis**

Objective: Analyze the response of the WTC towers to fires with and without aircraft damage, the response of WTC 7 in fires, the performance of open-web steel joists, and determine the most probable structural collapse sequence for WTC 1, 2, and 7.

### **Issue**

The principal issue here is to examine the NIST working hypothesis in conjunction with its collection of findings and to assess their consistency. The working hypothesis is found in June 2004 Vol. 6, Q-3.

The working hypothesis addresses the following chronological sequence of major events; specific load redistribution paths and damage scenarios are currently under analysis:

1. Aircraft impact damage to perimeter columns with redistribution of column loads to adjacent perimeter columns and to the core columns via the hat truss;
2. After breaching the building's exterior, the aircraft continued to penetrate into the buildings, damaging core columns with redistribution of column loads to other intact core and perimeter columns via the hat truss and floor systems;
3. The subsequent fires, influenced by post-impact condition of the fireproofing, further weakened columns and floor systems (including those that had been damaged by aircraft impact), triggering additional local failures that ultimately led to column instability;
4. Initiation and horizontal progression of column instability ensued when redistributing loads could not be accommodated any further. The collapses then ensued.

### **NIST Approach**

NIST and its contractors are using computational analyses to compute the impact damage by the aircrafts, the performance of a single floor truss under temperature elevation, the evaluation of a portion of the floor assembly in the ASTM E 119 test, and the history of the insulation applied in the WTC, especially to the floor assembly.

1. Impact computations: These computations are portrayed in figures on pp 78-79 of June 2004, Vol. 1, and they show an engine impacting and shredding a floor and then buckling a core column.

NIST reports further (June 2004, Vol. 1, p 81):

- A 500 mph engine impact against an exterior wall panel results in a penetration of the exterior wall and failure of impacted exterior columns. If the engine does not impact a floor slab, the majority of the engine core will remain intact through the exterior wall penetration with a reduction in velocity of about 10 percent and 20 percent. The residual velocity and mass of the engine after penetration of the exterior wall is sufficient to fail a core column in a direct impact condition. Interaction with additional interior building contents prior to impact or a misaligned impact against the core column could change this result.

Also an analysis of the stability of the towers, assuming no damage to the core, gives the number of floors that need to be removed to cause global failure (June 2004, Vol. 1, p.81)

The following presents some preliminary findings obtained from the preliminary stability analyses under service live loads and subject to the assumptions and the limitations of these models (see Appendix D): Linear stability analysis was used to examine the stability of the undamaged WTC 1 under service loads through increased un-braced column lengths (floor removal). The tower was stable when two floors were removed. Two core columns buckled when three floors were removed, but the tower maintained its overall stability. The tower also maintained its stability when four columns buckled with four floors removed. The analysis suggested that global instability of the tower occurred when five floors were removed from the model. Assuming that all columns at the region of the removed floors reached a temperature of 600 °C (reduced modulus of elasticity), the analysis indicates that removal of four floors would induce global instability.

2. Single truss analysis: A model of a single truss and its connection shows that the truss fails at the interior column seat connection, and ‘walks off’ the seat. This occurs at 650 C. The web diagonals begin to buckle at 340 C, and the exterior columns bow inward at 560 C causing the truss to act as a catenary. (June 2004, Vol. 1 p. 120).
3. E 119 tests: Standard fire tests were conducted at UL. Two were done at a 35 ft span representing the short span in the WTC towers. These had  $\frac{3}{4}$  in. thickness of insulation applied. A third test was conducted with public viewing with  $\frac{1}{2}$  in. insulation, and at a span of 17 ft. In that test the truss was scaled –down so that it was half its depth. The failure criterion used was primarily structural integrity for the most part. The third test was conducted *restrained* and obtained a 2 hour restrained rating meaning it did not structurally collapse, and it obtained a 1 hour unrestrained rating which results from exceeding a critical temperature of the steel.

4. Insulations history: NIST has traced documents and recommendations related to the thickness of insulation, particularly on the floor joist assembly. They have found and stated the following:
- a. The truss specified thickness was 0.5 in., but as applied was 0.6 +/- 0.3 inch.
  - b. The upgraded truss insulation was 1.5 inches (based on UL G805, May 2003, p. 78), but was later measured in application as 1.7 +/- 0.4 inches based on photographic analysis, but was reported in audit documents over 1997 to 1999 as 2.5 +/- 0.6 inches, with thickness as high as 4 inches (June 2004, Vol. 4, I 15-18).
  - c. A model code recommended 2 inches for 2 hours in a 2001 assessment of a similar truss (June 2004).
  - d. A report by Burro-Happold recommended in 2001 that the upgraded insulation could be dropped to 0.5 inches based on an ambient value of the conductivity used in a calculation, but settled on a recommendation of 1.3 inches. (May 2003, p. 82)

### **Questions**

Column impact: It is very important to determine an accurate estimate of the core column damage. In view of the variability of the impact computer codes, what does NIST consider is their accuracy? It was reported by the NY Times that the Weidlinger computations indicated that the South tower would fall solely upon impact of the aircraft. It is known that calculations were made in 1966 that indicated only local damage would occur. Why is there so much variability in these computations? In addition, the NIST reported results indicate that an engine needs to directly strike a core without loss of momentum for the column to fail. This would suggest very limited core column damage is possible as might be inferred from the NIST computational graphic shown above. Can an engine possibly hit a core column without hitting anything on the floor occupancy and structure? That does not seem possible, so how can an engine damage a core column? Perhaps I am missing something. Why is NIST then considering in its “working hypothesis” that considerable core damage is likely? Moreover, it is known that landing gear and at least one engine was found in the surrounding streets suggesting a flight path through the building. Can NIST use information on the location of the engines to assess the likelihood of core column damage?

Temperature importance for floor failure: The single truss analysis done by NIST and the work done both Usmani et al, and Burgess et al., indicate that the truss deflections occur at temperatures ranging from roughly 400 to 600 C. During these deflections, the truss can cause failure to its connections, or to column instability. It would seem that temperature is a key feature in causing failure. How does NIST relate its work to those cited above in the literature? If one floor falls on the floor below while both are heated by fire, can the impacted floor carry the load? Will this be a mode of global collapse? NIST considers the number of floors to be removed before the columns would become unstable, but would not the loss of 2 or 3-floors cause the failure before this instability? Is a critical temperature a good measure of structural failure as it might appear from the element computations, and the implication of the loss in strength at elevated temperatures?

Role of E119: Ratings have been achieved at UL for the E-119 test. Will NIST be analyzing these results to see how they would apply to the WTC? If the temperatures reached by the steel in these tests is sufficient to cause failures in the WTC computations, but the structure did not fall in the E 119 test, how will NIST reconcile these differences? NIST scaled the depth of the truss to ½ full-scale in its 17 ft E 119 test. This was done for stress purposes, but the heat transfer along the web into the concrete deck is now changed. Since temperature is a criterion for failure of the test in some modes of testing, the temperature of particularly the full-scale 35 ft. truss should be examined. Moreover, as UL G805 was used for justifying the 1.5-inch insulation thickness, why would the recent tests give such different results? Also UL N 826 might have been more appropriate, and gives 2 1/16 inches. So what is the meaning of the E 119 test and how should it be used in this WTC analysis?

Reconciliation of insulation thicknesses: As seen by the various E 119 results for the Cafco insulation, and the varied specifications and recommendations on the WTC truss insulation, it is incumbent on NIST give some rationality to these variations. Since the amount of insulation is so crucial to the outcome of finding the cause, NIST needs to be very sure about how much insulation was actually in place. The latest information from PANYNJ indicates that the upgrade in WTC 1 could have been as much as 4 inches over

the 1.5 specification, when field workers were having difficulties in application, and that was the main reason for the Burro-Happold report. A 4-inch radius on a 1 inch steel rod would give a 9-inch diameter cylinder – a very big result. How much confidence does NIST have on these large amounts? Do they have photographic evidence as in the previous smaller amounts? Would not a hearing on the insulation thickness issues serve NIST well in documenting the facts and rationality of these variations? If so much variation occurred for the WTC, how does this relate to the protection in other buildings?

### **Comments**

It appears that NIST has to answer some very focused questions with clarity and accuracy.

1. How many core columns were removed and why?
2. How much insulation was in place during the fire?
3. What are the critical temperatures needed for failure?
4. Could the fire cause these temperatures?

The global collapse mechanism of the buildings must be made as clear as possible. A vague answer expressed by the current NIST working hypothesis is not sufficient. NIST has expended a lot of good individual effort, and it has done some very good fact finding and analyses. Now all of that has to be put together, and it seems contractors (who we have not heard from) play a significant role. NIST needs to harness those individual efforts and expertise in a balanced evaluation. Reliance solely on complex computer models should not be the sole basis of the answers. If the core of the answers are really revealed and understood, NIST should be able to explain them in simple fundamental physics, and not shroud them in computer graphics. This was the purpose of the investigation, and this project task is critical.

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### III.

#### **Jack Murphy: Review of the NIST WTC Investigation; Comments and suggestions regarding projects 4 & 8.**

**October 13, 2004**

##### **Project #4 - Investigation of Active Fire Protection Systems**

- **The FAS audio/voice capability that was lost when the risers were shortened.** A recommendation for this vital component is to make all voice communications a feedback loop with a supervisory point just like other fire alarm devices in the system. The WTC had the capability if they lost a FAS sub-panel to back feed the information to the FCC. The fire alarm companies must give the same priority for redundancy to voice communication.
- **Fire Warden Phones [FWP] - not working above the point of impact.** A recommendation for the same redundancy as above. The phones must also have the capability from the FCC of activating more than the five floor limit to deal with today's emergencies. FWP also should be installed in no fewer than 2 stair tower risers when the stairs exceed more than 2. In the future we will need to consider installing a FWP in the elevator lobbies for the all-hazard evacuations.
- **Stair pressurization would have been ineffective in improving condition for occupants trying to exit.** A strong recommendation must be forthcoming from NIST on the value of constructing a fire tower. This would eliminate many of the issues related to stair pressurization.



## Project #8 - Fire Service Technology & Guidelines

- **FDNY Field Command Unit truck was not in service & recordings were not made of FDNY radio communications.** A recommendation that the FDNY must have the capability to record all radio transmissions from all field command unit is strongly encouraged.
- **Radio Readability Analysis** - of the 4 emergency departments responding on 9/11, FDNY units had begun to overwhelm the system within 4 minutes of the initial call. The initial response of 3 units at 08:46 hrs increased to 35 units at 08:50 hrs. The communication system needs then doubled 10-minutes later to 66 units and that in turn doubled to 121 units 5-minutes later at 09:10 hrs.
- **At 09:45 hrs a radio communication from a Port Authority Police Department officer reported that the 22nd floor exit door locks could not be released due to a loss of electrical power.** I suggest a strong recommendation that all stair tower doors be readily accessible at all times for any emergency. The fail-safe locking mechanism on these doors had many shortcomings. There are little or no standards for the installation and maintenance of these locks and fail-safe features. These systems have a high incidence of failures of emergencies.

**It is my hope that these issues can be focused on in the final NIST Investigation report and recommendations.**

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"Vigilance - The Act of Careful Watching": *Emergency Preparedness, Fire & Life Safety Practices and Professional Training*